Early Journal Content on JSTOR, Free to Anyone in the World

This article is one of nearly 500,000 scholarly works digitized and made freely available to everyone in the world by JSTOR.

Known as the Early Journal Content, this set of works include research articles, news, letters, and other writings published in more than 200 of the oldest leading academic journals. The works date from the mid-seventeenth to the early twentieth centuries.

We encourage people to read and share the Early Journal Content openly and to tell others that this resource exists. People may post this content online or redistribute in any way for non-commercial purposes.

Read more about Early Journal Content at http://about.jstor.org/participate-jstor/individuals/early-journal-content.

JSTOR is a digital library of academic journals, books, and primary source objects. JSTOR helps people discover, use, and build upon a wide range of content through a powerful research and teaching platform, and preserves this content for future generations. JSTOR is part of ITHAKA, a not-for-profit organization that also includes Ithaka S+R and Portico. For more information about JSTOR, please contact support@jstor.org.

Archaeological
Institute of
America

BROOKLYN MUSEUM MEASUREMENTS OF 1910 IN THE SPIRAL STAIRWAY OF THE PISA CAMPANILE[1]

RECENT and widely published anticipations of the possible downfall of the Pisa Campanile have had the result of reviving, or keeping alive, the general interest in the long-debated question whether its inclination is intentional or accidental.

Since the days of Vasari, a widely diffused, but by no means universally accepted, impression has prevailed that the tower settled " before it had attained half its height," and that it was then continued with a bend at the fifth story, intended to rectify partially the accidental inclination.

Vasari does not mention the reasons for his belief, and there is no historic record to support it. It may be concluded that the existence of the bend is the cause of his belief that the tower had settled. It is certain, at all events, that the existence of this bend, above the fourth story, has led many modern students to reach similar conclusions.

Now the fact must have been overlooked by Vasari, and has also been overlooked by the modern scholars who have held the same views and who have advanced the same argument, that the tower bends toward the perpendicular at *every story* above the first. Thus such modern scholars are not aware that the same logic and the same kind of reasoning which have inspired them to hold that the tower settled before it was finished, and after the fourth story was completed, must also compel them to hold that the tower had begun to settle *before the second story was begun.*

The earliest modern surveyors of the tower, Cresy and Taylor, did not measure and did not observe the bends toward the

---

[1] Paper read before the Archaeological Institute of America at the meeting at Providence, December, 1910.

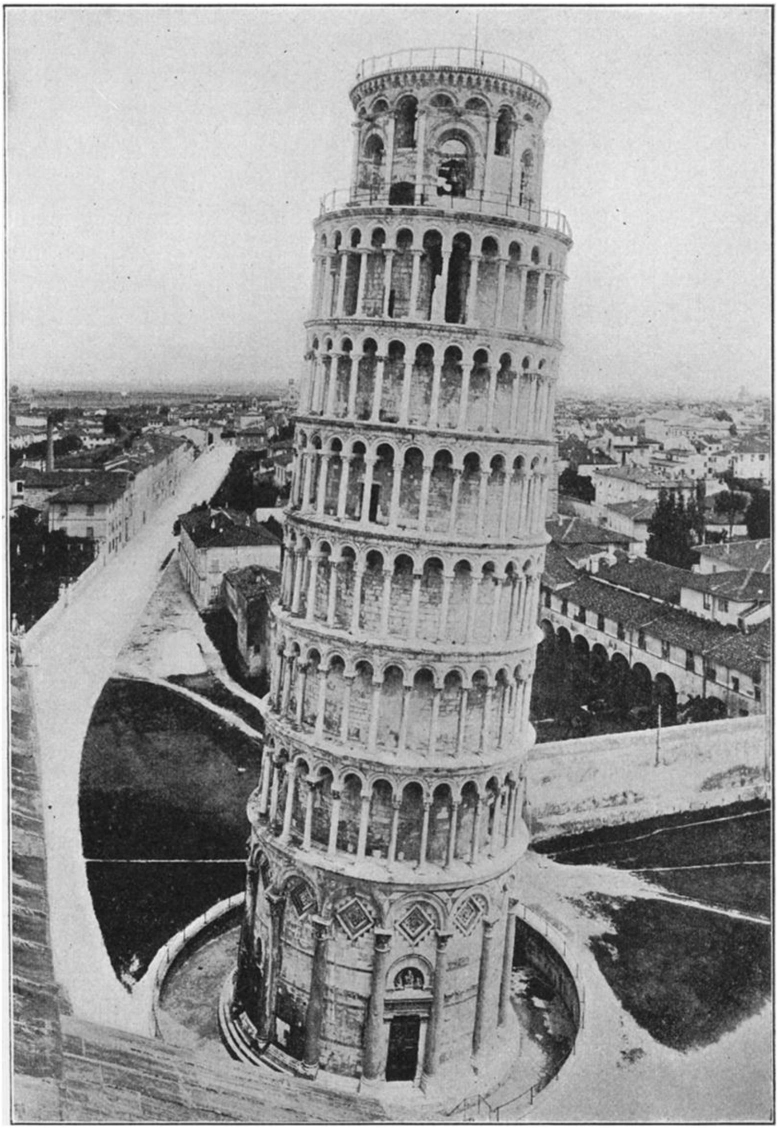

FIGURE 1. — VIEW OF THE LEANING TOWER OF PISA, SHOWING THE WELL IN WHICH IT STANDS.

(Brooklyn Museum Photograph, taken from the exterior choir gallery of the cathedral.)

perpendicular below the fifth story, and they also failed to record or observe the series of bends toward the perpendicular *above* the fifth story. So far as surveys are concerned, Rohault De Fleury was the first observer in this direction, although the facts are mentioned by Ranieri Grassi as early as 1837. De Fleury's section, published in 1859, demonstrates the existence of a bend at every story above the first (Fig. 2).

Rohault De Fleury applied to these bends the same logic and the same mode of reasoning which had apparently been applied by Vasari and by Cresy and Taylor to the single bend (at the fifth story) which they had observed. Just as Vasari held that the tower settled *when the fifth story was reached*, Rohault De Fleury held that a settlement began *before the second story was reached*, and all persons who hold to-day that the leaning tower is an accident are obliged to agree with Rohault De Fleury's theory of the accident.

It is certain that many who hold to the theory of accidental settlement are not familiar with Rohault De Fleury's results, but that simply implies that they do not understand their own case and do not know how that case has to be presented.

It is sufficient to say that De Fleury's theory has been formally accepted by Mothes, who is the compendious German authority on the statistics of mediaeval Italian architecture, and by Gsell-Fels, whose Italian guide-books are the best of their kind. It appears also in Venturi's recent history of Italian art. It is, moreover, the only possible theory of settlement.

What are the facts, in detail, on which that theory is based? What is that theory when stated in detail?

The facts are these. The bends toward the perpendicular are obtained by giving unequal and greater height to the galleries on the overhanging side, or south side, as compared with the north side (see Fig. 2). The extra increments of height on the south side are:

3 centimetres in the second story,
4 centimetres in the third story,
7 centimetres in the fourth story,
15 centimetres in the fifth story,
8 centimetres in the sixth story,
11 centimetres in the seventh story, and
38 centimetres in the platform of the eighth story.

The total extra height on the south side of the tower, as contrasted with the north side, has, therefore, the very considerable amount of *86 centimetres or 34 inches.*

Now what is the theory based on these facts? In stating this theory it must be remembered that it is to-day the *only possible theory of settlement* when the facts established by De Fleury's survey are known.

This theory is that a continuous settlement was in progress throughout the entire hundred and seventy odd years during which the tower was in process of construction, 1174–1350, and that the successive amounts of this settlement are determined by the successive amounts of the increments in the heights of the galleries on the overhanging side. For

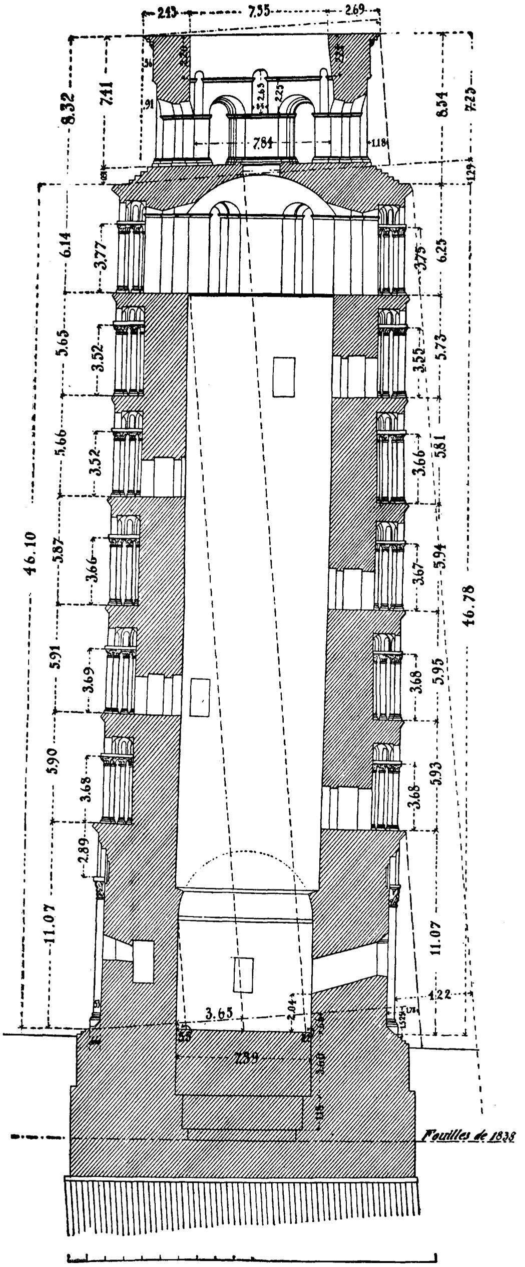

FIGURE 2. — DE FLEURY'S SECTION OF THE LEANING TOWER.

instance, the second story (first gallery) is 3 cm. higher on the south side, therefore an unequal settlement of 3 cm. had occurred before the second story was begun; and so on, for each successive disparity of measurements for the heights of the same gallery on opposite sides of the tower.

Thus when the seventh story was finished the tower had settled, according to this theory, to such an extent that its total inequality of settlement amounted to 50 cm., and all of this had been made good, according to this theory, by the corrections whose amounts up to that height have been mentioned. We might, therefore, suppose, as the platform of the eighth story shows an inequality of 38 cm., when its two sides are compared, that this was the additional amount of settlement just before that platform was reached. The theory of De Fleury presumes, however, that the inequality of settlement at this point was only 20 cm. and that 18 cm. of the 38 represented a downward slope of the platform in the direction opposed to the inequality of settlement, which was given by the builder in order to anticipate and forestall the downward movement on the south side. The reason for this presumption is that the eighth story or bell chamber *is 16 cm. higher on the north side* (7.41 m. – 7.25 m.). Therefore the theory stands as follows for the eighth story platform: the builder found a settlement, since the next story below was built, of 20 cm., but, besides correcting this, he added 18 cm. tilt *in the opposite direction*, so as to anticipate a further settlement, but it then turned out (the theory holds) that the builder allowed too much, and the actual settlement at this time was only 2 cm. up to the time when the tower was completed. Thus the platform of the tower sloped 16 cm. (or 18 cm. minus 2 cm.) to the north, and therefore the wall was made higher on the north side to the same extent, and, when the tower was finished, the top was level. The theory, therefore, holds that the tower was perpendicular at this date, apart from a bend convex to the exterior on the south side, which amounted to 30 cm. or 1 ft., and which was due to the successive rectifications which had kept the tower perpendicular.

Thus the total amount of unequal settlement when the tower was finished was 70 cm., *i.e.* 86 cm. minus the 16 cm. overplus tilt downward, toward the north, which the builder had constructed in anticipation of a settlement which did not occur at that time. But the total inclination of the lower platform of the tower was 1.50 m. in 1859. Thus the given theory holds that 80 cm. additional inequality of settlement occurred after the tower was completed.[1]

Now, if the theory of De Fleury and Mothes appears labored or complex, it must be remembered that no other settlement theory is possible when the figures are known. It would be a comparatively simple statement to say that the tower settled gradually, and unequally, 86 cm. before completion and the difference between 86 cm. and 1.50 m. after completion, and that the proof that it settled gradually lies in the figures for the heights of the galleries. This simple statement is, however, not sufficient. The settlement theory has to deal with the fact that the north side of the bell chamber is higher than the south side, and it can explain this fact only by supposing that the platform of the bell chamber was tipped too far in the opposed direction by a builder who was anticipating that something would happen which actually did happen at a later date, but which did not happen until after the tower was finished.

It is doubtful, however, if more than half a dozen scholars in Europe, out of the number of those who are familiar with De Fleury and Mothes, could give to-day any definite account of their own ideas about the accidental settlement of the Leaning Tower without first reading up on the figures in Mothes' or De Fleury's publications, and it is perfectly certain that the majority of experts who hold to the theory of accidental settlement have no idea whatever of the manner in which that settlement must have occurred, if it occurred at all.

There are certain improbabilities in the theory of settlement when the problem is stated explicitly, in the terms of De Fleury, Mothes, and Venturi, as it must be stated if stated properly.

That a leaning tower may be the result of accident is obvious, and this accident has evidently and obviously happened in many cases; but that the builders of such a tower should have striven continuously to correct a continuous and uninterrupted progressive movement which began before the second story was begun, is manifestly open to doubt. The ultimate downfall of the tower must have seemed as probable then, under the circumstances assumed to exist, as it would now seem to us, if a continuously progressive movement were now known to exist. The builders of the tower were obviously themselves good masons and good artists, and it seems most unlikely that they would have taken the risk. If the builders and masons had been so foolhardy as to take these risks, it is unlikely that the communal and ecclesiastical authorities and the contributors to the funds for the building would have allowed them to do so. Many of the Italian communes of this period had laws compelling the owners of towers which had weak foundations and which appeared insecure, to take them down in order to avoid accidents.[1] If such laws existed, is it likely that any Italian commune would have deliberately continued to build a tower which was threatened by an obviously imminent disaster?

---

[1] It is also generally agreed that this settlement must have occurred soon after the tower was finished; certainly a good while before the time of Vasari.

In order to appreciate the bearing of the measurements of the Pisa Campanile which were taken on behalf of the Brooklyn Museum in May, 1910, it is necessary to bear in mind the conditions of the problem relating to the tower, as they have been surveyed by De Fleury, and this is why these conditions have been so carefully rehearsed. If a settlement occurred at all, it must have begun before the second story was under way, and when the second story was under way, the unequal settlement cannot have been more than 3 cm., but there must also have been a direct downward settlement of very serious amount. According to the depth of the well in which the tower now stands (Fig. 1), the total settlement must ultimately have been at least 4 ft. on the upper side, and 9 ft. on the lower side. De Fleury holds, however, that the total settlement was 8 ft. on the upper side[2] and 13 ft. on the lower side, as he believes that the level of the platform of the adjacent cathedral choir was the original surface level of the Campanile.

Remembering, therefore, that the theory of accidental settlement must include the conditions of *direct* settlement as well as those of *inequality* of settlement, we now proceed to consider the measures of 1910 in the spiral stairway.

---

[1] Ricci, *Storia dell' Architettura in Italia*, vol. I, pp. 577–584.

[2] 2.40 m. See the text to his *Monuments de Pise*, p. 65.

The ground plan of the tower shows it to be a tube with an interior void. The ascent is made by a spiral stairway which is built in the tubular wall. The diagram (Fig. 3) is planned in outline like the ground plan. The measures on either side of each step represent the height of the ceiling of the stairway as measured at the centre of the side of each step. The measure *on* the step represents the average or mean height of the ceiling at the given step, and is obtained by dividing by two the sum of the outer and inner measures. It therefore gives the height at the middle of each step. The extreme outer circle of measures represents the excess of height on the

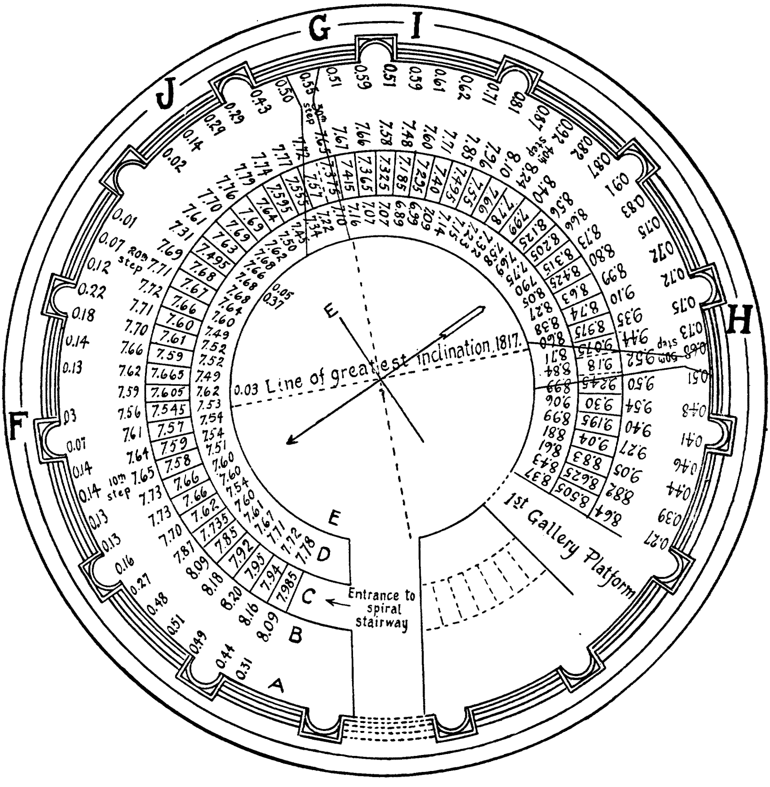

FIGURE 3.—LEANING TOWER; FIRST DIAGRAM.

outer side of each step wherever such excess is found. The first step, for instance, is 8.09 ft. high on the outer side, and 7.78 ft. high on the inner side. Therefore 0.31 ft. is the extra height on the outer side, and this measure represents that amount of tilt downward and inward of the ceiling. In cases where the inner height is the greater, for instance at the fourteenth step, where the inner height is 7.62 ft. and the outer height is 7.59 ft., the difference is 0.03 ft. greater height on the inner side. This measure is placed on the diagram in the inner circle, just inside the bounding line of the wall which surrounds the well. At the given point the ceiling tilts downward in the outward direction to the amount of 0.03 ft.[1] It

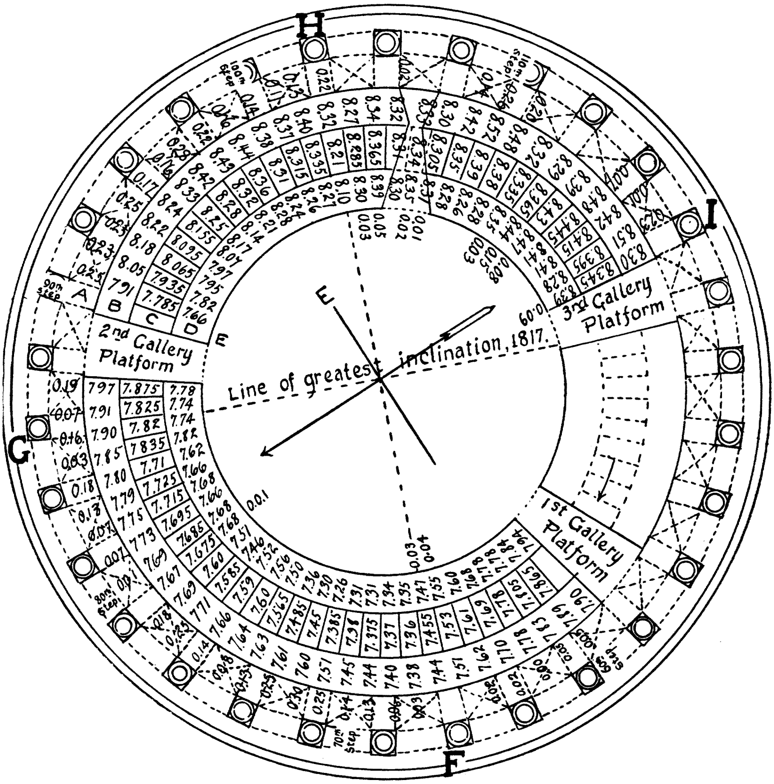

FIGURE 4. — LEANING TOWER; SECOND DIAGRAM.

---

[1] As compared with the step.

may be noted that there are only three measures on this diagram which show this kind of tilt.

This diagram also shows the line of greatest inclination from N. E. to S. W. The thirteenth step is the point of greatest inclination on the side opposed to the overhang. The forty-ninth step is the point of greatest inclination on the side of the overhang. The measures on this diagram end at the first gallery platform.

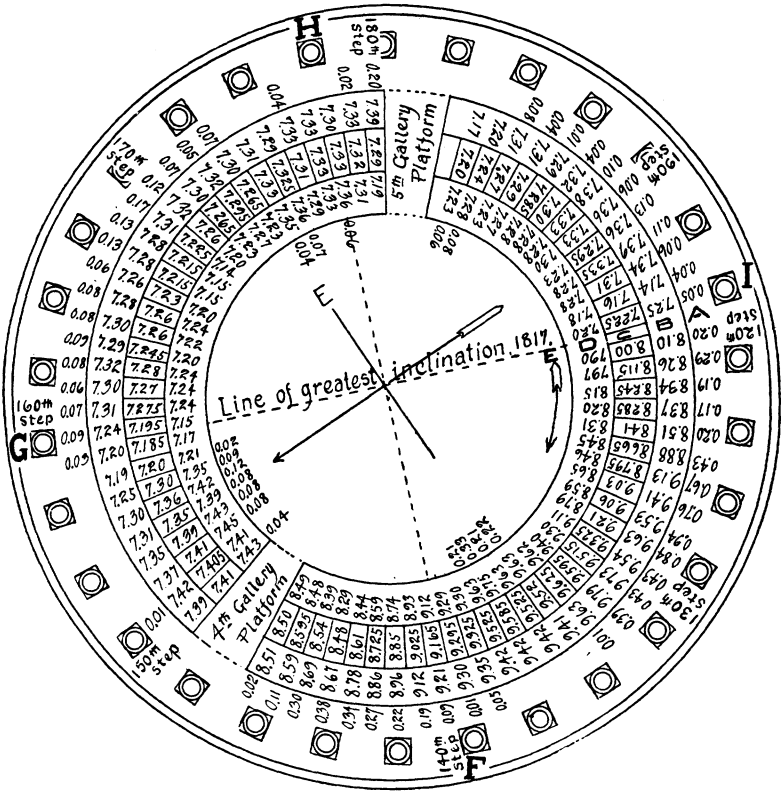

Figure 5. — Leaning Tower ; Third Diagram.

The next diagram (Fig. 4) is designed on the same principles, and continues from the first gallery platform around to the second, and then to the third gallery platform.

The third diagram (Fig. 5) begins at the third gallery platform. It rises to the fourth gallery platform, then to the fifth gallery platform, and beyond it.

The fourth diagram (Fig. 6) completes the series of measures for the twenty-two remaining steps of the entire two hundred and seventeen, up to the platform of the sixth gallery or seventh story. Beyond this platform the bell chamber is reached by a very small spiral stairway which is built inside one of the piers which support the platform of the bell chamber.

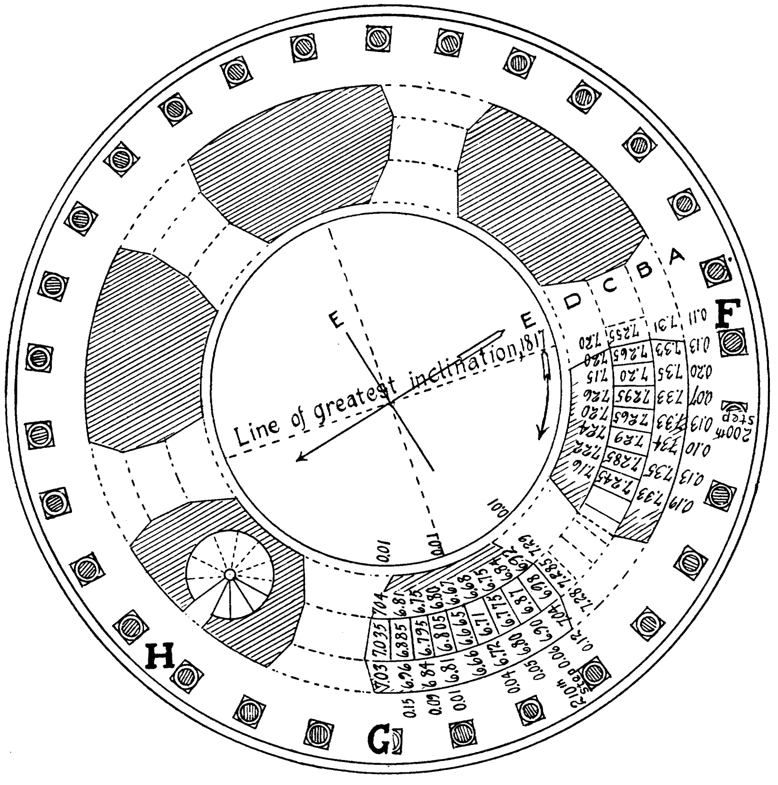

Figure 6. — Leaning Tower; Fourth Diagram.

In considering these measures, we have first to ascertain what allowance should be made both for errors of the surveyor and for errors of the builders. These measures are given in feet and foot hundredths, and it is evident that no builder could intentionally build variations of only a few hundredths of a foot. The question therefore rises: Beyond what limits of variation can we assume intention? Moreover, allowance must be made for errors of the surveyor. The measures were taken with a sliding surveyor's rod and read from a vernier. The position of the rod was determined by the eye in placing it at the centre of each step, and, whereas the surface of the step is flat, the rise of the ceiling is continuous. For instance, at the fifty-second step the amount of rise is 0.46 ft. in a width of 1.60 ft.; or, say roughly, 6 in. in 18 in. If an error of an inch were made in placing the rod, there would be an error of $\frac{1}{3}$ of an inch as regards the height of the ceiling.

The allowance for these errors may be easily calculated on the third diagram (Fig. 5). The mean height of the ceiling at *G* is 7.195 ft. and at *I* it is 7.225 ft. There are thirty-seven steps between these points, and yet the difference of height is only 0.175 or $\frac{3}{8}$ inch. It is evident that the ceiling was intended to be of equal height between these points, and that the builders were in error in a distance of thirty-seven steps by only $\frac{3}{8}$ inch. In the given thirty-eight steps the greatest variation in height is $2\frac{3}{8}$ in.,[1] and the greatest variation in tilt of the ceiling is $3\frac{3}{4}$ in.[2] The variation in dip between the first and last steps of the thirty-seven is only 0.04 ft., or half an inch.

Therefore, if the height of the ceiling rises, in the first story (Fig. 3), 1 ft. 6 in. between the thirteenth step and the forty-ninth step, we know that the rise was intended. And if the inward dip of the stairway ceiling, in the first story, increases $8\frac{1}{4}$ in. between these points, we know that this increase was intended, and that the dip itself was intended.[3]

The purpose to be served by an inward dip of the ceiling in the case of a leaning tower is very apparent. If the stairway ceiling tips downward and inward, at the forty-ninth step, over

---

[1] 7.335 (one hundred and ninety-second step); 7.16 (one hundred and ninety-fourth step).

[2] 0.20 ft. dip inward (one hundred and eightieth step); 0.12 ft. dip outward (one hundred and fifty-fifth step).

[3] The unbroken series of increments in height begins at the thirty-fourth step (at *I*). The measures for mean increase at each step, from this point, are as follows: 0.11, 0.105, 0.095, 0.055, 0.11, 0.12, 0.21, 0.135, 0.08, 0.11, 0.11, 0.205, 0.11, 0.235, 0.10. The uninterrupted increase in the dip begins at the twenty-fifth step (*J*). See Fig. 3.

8 in. in a stairway width of only about 3½ ft., it is evident that the weight of the masonry above the ceiling is thrown toward the inner wall, and that this is an advantage to the solidity and strength of a leaning building. That this inward dip of the ceiling is a constructive device for obtaining additional solidity and forestalling any outward movement of those parts of the wall which are adjacent to the pressure on the stairway ceiling, is self-evident. The advantage of this device for all parts of the tower, excepting those which are quite near to the point which is directly opposed to the overhang, is also apparent.

As regards the variation in height of the stairway ceiling, it appears, if the height of the ceiling rises toward the overhanging side, that the weight of the masonry is diminished as much as the void space is increased, which amounts to the same thing as adding to the weight of the masonry on the side opposed to the overhang. A simple calculation will show, if the ceiling rises to the amount of 1 ft. 10 in., and this is the case between the thirty-fourth step (*I*) and the forty-ninth step (*H*), that there is a diminution at the forty-ninth step *alone*, of about 11 cubic feet of masonry, and that, for this one step, 11 cubic feet of masonry are added to the weight of the tower on the side opposed to the overhang. By similar calculations for the individual steps, it is easy to understand that a very considerable change in the centre of gravity of the tower has been effected by this arrangement.

The question now arises, what could be the reason for weighting the tower more heavily on one side than on the other, and the choice of reasons must evidently lie between two. One reason might be suggested, that the device was intended to combat an unequal settlement; or, at least, we will assume that this reason might be suggested. The only other possible reason would be the desire to give additional security to an intentionally leaning construction and to shift the centre of gravity to the north of what might be termed the mathematical centre.

If the first reason is abandoned, the second reason must be accepted. But the measures show that the system of decreasing the height of the stairway began at the first step. There is a gradual diminution of 5½ in. in mean height between the first step and the thirteenth step. The inauguration of the system at the beginning of the construction is also most convincingly proved by examining the measures for the inward dip of the ceiling. Between the third step and the thirteenth step, which is the central point opposed to the greatest overhang, the inward dip decreases from 6 in. to nothing. The results of this observation appear conclusive as to intentional construction.

For the alternative is not only that a settlement had begun when the first step was laid, *but also that the builders knew before they had reached the thirteenth step which way the tower was ultimately going to lean.*

We must remember that the inequality of settlement was never as great as the direct settlement. The direct settlement *on the upper side* was ultimately 8 ft., according to De Fleury. But the inequality of settlement was only 3 cm. or about an inch, *when the first story was finished.* We must, therefore, suppose, on the theory of accident, that the builders knew which way the tower was ultimately going to lean when they began the building, although the inequality of settlement was only about an inch when they had finished the first story.

In cases of settlement there must naturally be some inequality, and this inequality would naturally affect different points at different times in the progress of the settlement. No builder could possibly have known which way the first story was going to tip before the thirteenth step was reached.

This argument appears conclusive, and it only remains to expand and supplement it by an account of the measures above the point of greatest inclination in the first story, at the forty-ninth step.

The decrease in height begins at the fifth step beyond the point *H*, and this decrease is shown, partly by the first diagram (Fig. 3) and partly by the second diagram (Fig. 4), to be continuous around to the quarter turn on the west side on the second diagram, near the point *F*. The height of the stairway then remains without systematic change as far as the point *G* at the eighty-sixth step, the point opposite the middle of the overhang. Beyond this point there is a gradual rise of 6 inches around to the point *I*, at the third gallery platform, which is the central point of the overhang, thus repeating the same expedient, but in less amount, which was observed in the first story.

In order to study the dip of the ceiling above the forty-ninth step (at *H*, Fig. 3), we now return to that point. The decrease in the dip begins near the forty-ninth step, and is continuous around to the west quarter turn on the second diagram (at *F*, Fig. 4). But beyond this point the system of dip variation is abandoned, and the figures generally show a very slight inward dip, with slight changes which are not systematic.[1]

---

[1] The accounts of Mothes (*Die Baukunst des Mittelalters in Italien*, II, p. 737), who is the best authority in such matters, make it possible that Bonanno, the first architect of the tower, was absent at Monreale, near Palermo, during the construction of the next story (third galllery). At all events, it is certain that the construction came to a halt in 1186 until 1233, after the fourth story (third gallery) was finished. This period of inactivity thus lasted about fifty years.

Beyond the third gallery platform (Fig. 5, *E*, *D*, *C*, *B*, *A*) the mean height of the stairway rises very abruptly from 8 feet at the one hundred and twentieth step, next the platform *E*, *D*, *C*, *B*, *A*, to 9.625 ft. at the one hundred and thirty-third step. The mean height then decreases to 8.50 ft. at the one hundred and forty-eighth step, next the fourth gallery platform.

We may assume that the increase in the height of the stairway on the west side was originally intended to be continuous throughout the remainder of the construction, and that it was intended to diminish the weight of the wall in the upper stories. Several other effective expedients were undoubtedly employed to that end, especially the successive reductions in the thickness of the tubular wall. These reductions in the thickness of the wall probably made the continuance of the high stairway inadvisable, as the main upper weight of the tower had to be supported by these narrow walls. The thickness is only about 2 ft. 3 in. in this story.

Whether the expedient was abandoned by its original devisers or by builders who followed them at a later date, cannot, of course, be determined. The temporary revival of the dip system in connection with the rise of the ceiling in the quarter turn on the overhanging side, from the one hundred and twentieth to the one hundred and thirty-second step (between *I* and *F*, Fig. 5), speaks for itself in the measures. This was certainly suggested by considerations relating to the danger of an outward movement of the high wall of the stairway, and in view of its diminished thickness.

It is also extremely significant that, when the fourth gallery platform was reached, the stairway was lowered an entire foot, as between the steps on either side of the platform (8.50 ft., one hundred and forty-eighth step, lower side; 7.41 ft., one hundred and fiftieth step, upper side). Such an abrupt change of height is otherwise wholly foreign to the system of the stairway. A new architect, Benenato, took charge of the construction above the fourth gallery platform in 1233, and this lowering the height of the stairway by 1 ft. (1.09) was therefore due to him. The fifth gallery (sixth story) was not begun until 1260. This and

Thus, above the third gallery platform the systematic variations in the height of the stairway and in the dip of its ceiling are abandoned. From this fact an additional argument may be derived. The third gallery platform is the top of the third story, and reference to De Fleury's section shows not only that the exterior bends continue above this point, but also that they increase in their amount. If it be held that both devices, viz. the system of changes in the interior height and dip of the stairway and the system of exterior bends, were intended to counteract a continuous settlement, then it would be impossible to explain why one system was abandoned above the third gallery platform, and why the other was continued. But if it were held that both systems were intended to secure the stability of an intentionally leaning construction, then the explanation would be simple. This explanation naturally considers the point that the variations in the height and dip of the stairway must have given the builders considerable trouble and must have caused considerable extra expense.

The explanation would be that the stability of the experiment was established when the third story was finished, and that anxiety about it had disappeared. From this point of view, the explanation of the exterior bends would be that the builders had wished to accent the impression and appearance of inclination at the base of the tower, and had also wished to slightly and imperceptibly diminish the inclination as the height of the tower increased, as a precaution affecting the centre of gravity. From the same point of view, the downward rake to the south given to the top of the upper story would be also easily explained. This increase in the height of the north side of the bell chamber was a device which did not at all affect the stability of the tower, but it tended to conceal the rectification toward the perpendicular. In other

the sixth gallery (seventh story) were built by Wilhelm von Innsbruck. The bell chamber, by Tomasso da Pisa, was not built until about 1350.

Beyond the point *G* in Figure 5 the measures have been already analyzed, and it was from these measures, for the stairways of the fifth and sixth galleries, that we were able to determine the extreme limit of builders' and surveyor's errors for the lower stories of the tower. There is no further significant change in the height of the stairway, and this applies also to the twenty-two steps which are shown in Figure 6.

words, it exaggerated the appearance of inclination, but did not actually increase it.

It must be admitted that the explanation of Mothes for this feature of the construction is rather fanciful.

Ranieri Grassi, who was the most vigorous exponent in modern times of the theory of the intentional inclination of the Leaning Tower of Pisa, and who was the first observer of the facts relating to the changes of height in the spiral stairway and in the dip of the ceiling, adduced another argument which deserves serious attention. Grassi quotes Michele da Vico, an author of the fourteenth century, as expressly mentioning the strength of the foundations and the fact that they were allowed to rest for a year before the construction was undertaken.[1] The tower was finished in the middle of the fourteenth century; therefore, says Grassi, da Vico could not have praised the foundations if the tower had settled, and, if it had settled, he assuredly would not have described the foundations without mentioning a settlement.

The arguments recently advanced by the Italian Government Commission as demonstrating accident do not appear to have great weight. The discovery that the foundations (of masonry) are only 3 m. deep is held to demonstrate their weakness, but the history of the tower, which is known not to have changed its inclination for many centuries before the movement which was probably caused by the earthquake of 1846, demonstrates that this depth was sufficient.

Moreover, the authority, Rohault De Fleury, who committed the error of representing the foundations as being 7 m. deep, was himself a supporter of the accident theory.

It has also been found by the Pisa Commission that the foundations are of equal depth on all sides, *i.e.* the base of the foundations slopes like the base of the tower. This is held by the Commission to be a proof of settlement. But if the base of the foundations had been level, they would have been of unequal depth, and therefore of unequal strength, and the weaker side would also have been the side of the overhang, where strength is most to be desired.

---

[1] *Descrizione di Pisa et suoi Contorni*, vol. II, p. 96, 1837.

The truth seems to be that the only logical argument for an accidental settlement is that of De Fleury, and that the logic of this argument is its own destruction when it is applied to the recent measurements in the spiral stairway.

William H. Goodyear.

Museum of the Brooklyn Institute.